The Multiplicative Power of Masks

An Explorable Essay on How Masks Can End COVID-19

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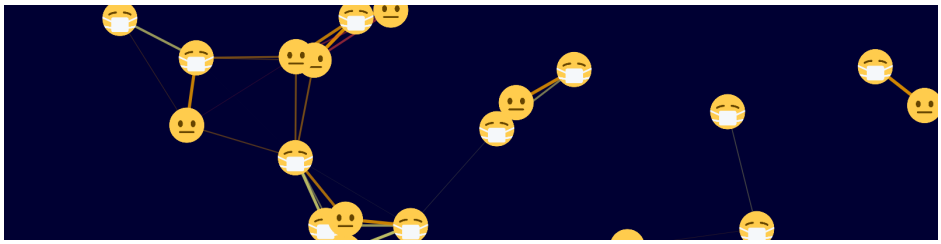
We now know that masks have an outsized effect on slowing the spread of COVID-19. And yet, some people oppose wearing masks because they view this as a personal choice rather than a public health issue.

This misses the big picture because masks protect the wearer *and* the people around them. This two-way protection makes widespread mask-wearing a powerful way to extinguish an epidemic.



By doing the math on masks, we'll see how when 60% of people wear 60% effective masks, disease transmission drops by as much as 60% — roughly what's needed to stop the spread of COVID-19.

Watch the companion video: Why Masks Work BETTER Than You'd Think

Say it, Don't Spray It

But first, let's get a ballpark sense for some numbers. When a person exhales,

they spray out saliva particles of various tiny sizes. If they're contagious, then this 'mouth spray' is loaded with viral particles. This virus-laden saliva spray is the main way that COVID-19 spreads.

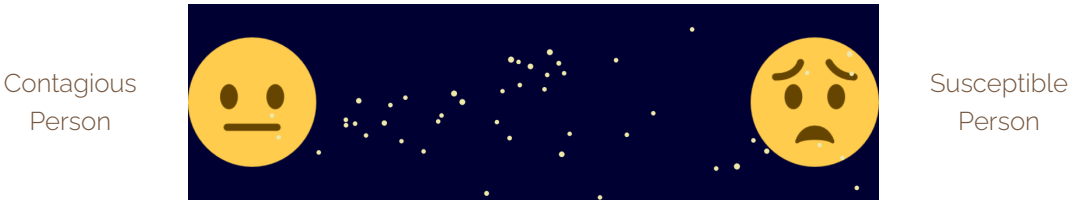
When a contagious person breathes, they spray out roughly **a thousand** viral particles every minute.

When they talk, they spray out roughly **ten thousand** viral particles every minute.

When they cough, they spray out roughly **a hundred thousand** viral particles.

And when they sneeze, they spray out roughly **a million** viral particles.

The more viral particles travel from person to person, the higher the chance of infection. (And if infected, people exposed to more viral particles generally experience more severe symptoms.)



Transmission Route 1: When a contagious person is near a susceptible person, their 'mouth spray' can spread disease.

Masks reduce the mouth spray traveling between people — by blocking or by redirecting the spray — thereby reducing the chance of infection.

It's worth keeping in mind that no mask is perfect. Even the N95 masks recommended for health workers are only guaranteed to block 95% of the hardest-to-block particles (and that's only if you wear them correctly).

Masks don't guarantee safety, they reduce risk. This is a lot like how an umbrella doesn't guarantee that you'll stay dry, but it does reduce your chance of getting wet. Like umbrellas, masks only work if you use them correctly. But unlike umbrellas, which only protect people who use them, masks also protect people *around* the wearer.

Why Masks Protect Us Twice

Let's imagine that a contagious person wears a 50 percent effective mask. By '50 percent effective', I mean that wearing this mask cuts in half the chance that they'll infect a nearby susceptible person.

Transmission Route 2: When the contagious person wears a 50% effective mask, disease transmission drops by 50%.

But what if the susceptible person wears the mask instead?

In general, the effectiveness of a mask depends on whether you're **inhaling** or **exhaling** through it. For now, let's keep things simple and assume that this mask is equally effective in either direction.

In that case, the chance of infection in this route also drops by 50%.

Contagious Person

Susceptible Person

Transmission Route 3: When the susceptible person wears a 50% effective mask, disease transmission drops by 50%.

What if both the contagious *and* the susceptible person wear a mask?

Well, the first mask cuts the chance of infection in half, and the second mask once again cuts the chance of infection in half. So when *both* people wear masks, the chance of infection is half of half, i.e. 25% (as compared to when neither wear masks). That's a 75% drop in the chance of infection.

Contagious Person

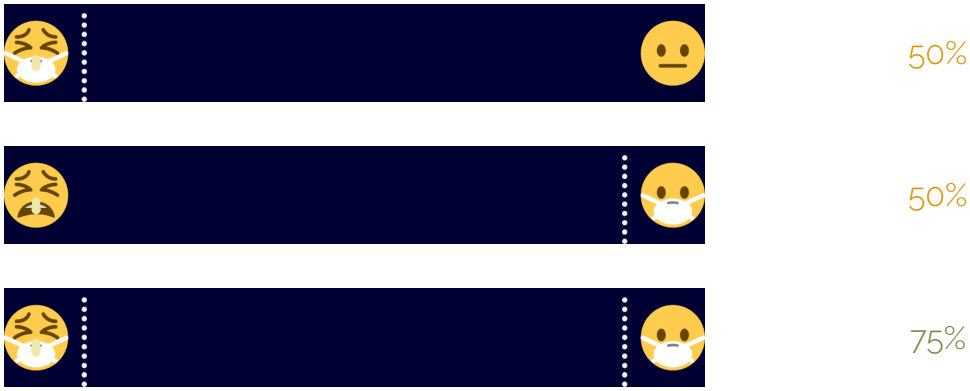
Susceptible Person

Transmission Route 4: When both people wear 50% effective masks, disease transmission drops by 75%.

If you think about it, it's surprising that a 50% effective mask can reduce the risk of infection by 75%. This is possible because when both people wear masks, the chance of infection is halved twice. This **double protection** makes masks much more effective than you might intuitively expect.

So here are all four routes through which an airborne disease can spread from person to person.

Disease Transmission Route	Drop in Disease Transmission
	0%



The four ways that COVID-19 can spread from person to person.

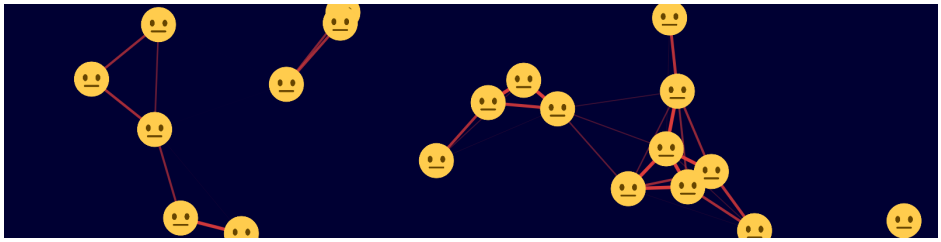
This assumes a 50% effective mask.

From People to The Population

So far, we've only looked at disease transmission between two people. How do we go from here to understanding disease transmission in the *entire population*?

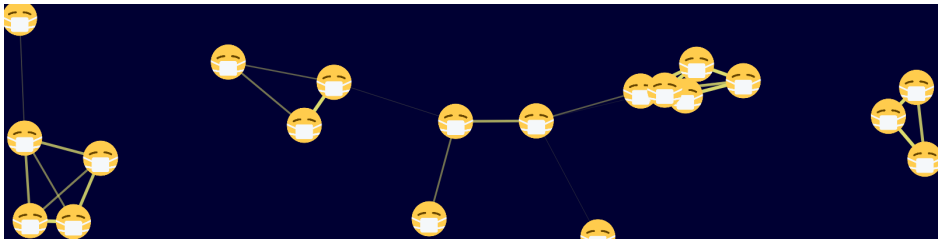
Well, in the extreme limits, this is straightforward.

For example, if **nobody** wore a mask, then whenever two people meet, the chance that neither wear a mask is 100%.



So we'd only have to consider the first route of disease transmission, and the population would see no drop in disease transmission.

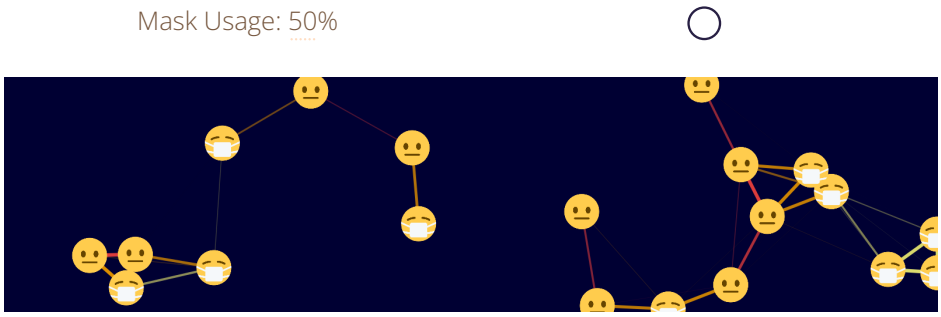
At the other extreme, if **everyone** wore a mask, then whenever two people meet, the chance that they both wear masks is 100%.



In this case, we'd only have to consider the last route of disease transmission. Assuming masks are 50% effective in each direction, the population would see a 75% drop in disease transmission.

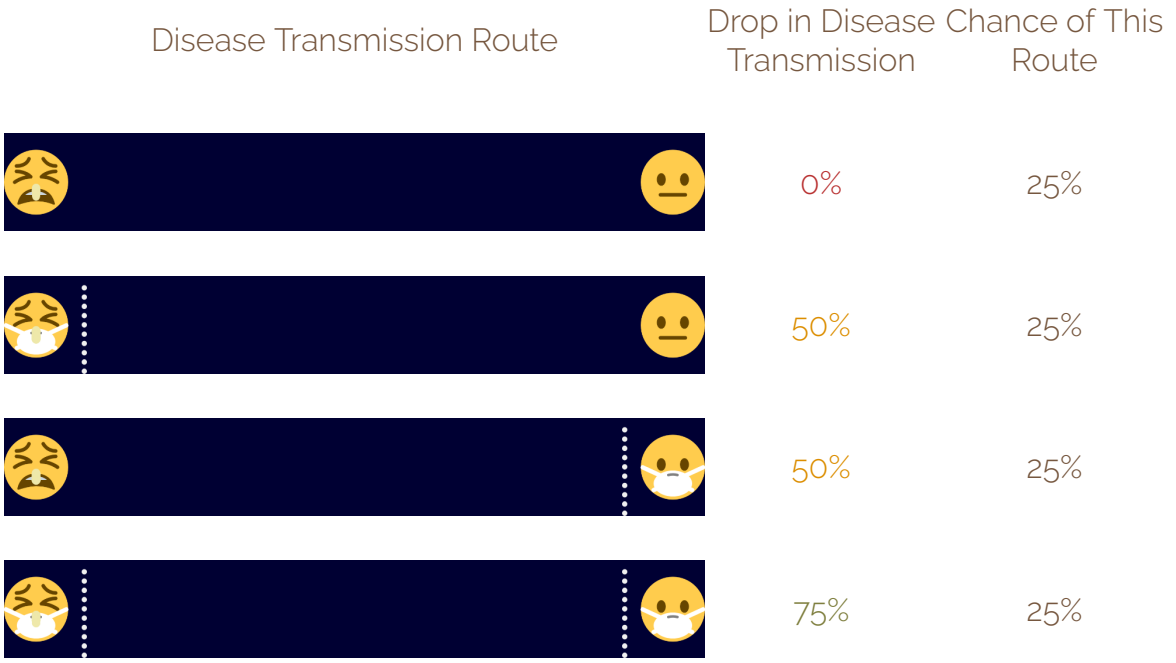
So when *everyone* wears a mask (or when *no one* wears one), it's straightforward to calculate the drop in disease transmission in the population, because there's only one route involved.

But in reality, some people wear masks and others don't. Which means the virus can spread through a mix of all four routes. How likely each route is will depend on how many people wear masks.



For example, **if 50% of people wear masks**, then whenever two people meet at random, the chance that both people wear masks is 50% × 50%, i.e. 25%. Similarly, you can work out the chance of the other three disease transmission routes.

When exactly half the population wears masks, it turns out that each route is equally likely. (Can you convince yourself why this has to be true?)



The four ways that COVID-19 can spread from person to person, assuming that 50% of people wear a 50% effective mask.

We can now calculate the **average drop in disease transmission in the population**. Since we've set things up so that each route is equally likely, this is just the average of 0%, 50%, 50% and 75%, which is 43.75%.

People who *don't* wear masks get infected via the first two routes, which are equally likely when half the population wears a mask. So the drop in disease transmission to non-mask wearers is the average of 0% and 50%, which is 25%.

Meanwhile, people who *do* wear masks get infected via the last two routes. So the drop in disease transmission to mask-wearers is the average of 50% and 75%, which is 62.5%.

Average Drop in Disease Transmission = **43.75**%

Drop in Disease Transmission to **Non-Mask Wearers** = 25%

Drop in Disease Transmission to **Mask-Wearers** = 62.5%

(Assuming 50% of people wear a 50% effective mask.)

So even non-mask wearers get a modest benefit, because the air they inhale is often mediated by *other people's* masks. But mask-wearers benefit much more, thanks to the added protection their masks provide.

And since the population consists of both mask-wearers and non-mask wearers, the average benefit lies in between the benefit to these two groups.

So in this simplified example (where 50% of people wear 50% effective masks) we've worked out how to go from the **benefit that masks offer an *individual*** to the **average benefit that masks offer a *population*.**

Maskology

Let's apply this logic to *any values* of **mask usage** and **mask effectiveness**. Vary the sliders below to see how masks moderate the spread of disease.

Mask Usage: 50%

Mask Effectiveness on Exhale: 50%

Mask Effectiveness on Inhale: 50%

Disease Transmission Route	Drop in Disease Transmission	Chance of This Route
	0%	25%
	50%	25%

50% 25%

75% 25%

Average Drop in Disease Transmission: **43.8**%

Drop in Disease Transmission to Non-Mask Wearers: 25%

Drop in Disease Transmission to Mask-Wearers: 62.5%

What happens to disease transmission if 60% of people wear a 60% effective mask? Or 90% wear a 50% effective mask? Or 50% wear a 90% effective mask? This interactive lets you answer these questions.

The conclusion: **When more people wear masks, everyone is safer.**

By filtering inhaled air, masks provide first-hand protection to those who wear them. And by filtering or redirecting exhaled air, masks provide second-hand protection to *everyone* — including people who don't wear masks.

What about masks that don't filter exhaled air? (Click to expand)

In fact, masks are even more effective than these numbers suggest.

How To Stop An Epidemic

You put out a fire by starving it of oxygen. But you don't need to get rid of all the oxygen, you only need to reduce it enough to stop the fire from growing. It's the same with an epidemic — you don't need to cut disease transmission by 100%. If you lower it just enough to stop the disease from spreading, you can extinguish the epidemic.

You've probably heard of the epidemiology term R0, pronounced R-nought or R-zero. This is the number of people that a contagious person can infect in a population with no prior immunity to the disease.

When R0 exceeds 1, the disease will grow exponentially until either enough people get vaccinated, or enough people get infected and develop immunity to the disease.

But, as Ed Yong writes in the Atlantic, "R0 is not destiny". R0 is a product of two numbers: the average number of people that a contagious person encounters, and the chance of infection upon contact.

R0 = average number of people that a contagious person encounters
× chance of infection upon contact

Social distancing, quarantines, and lockdowns decrease the first number. And

masks decrease the second number. The goal of all these public health strategies is to bring the epidemic under control by pulling R0 beneath 1.

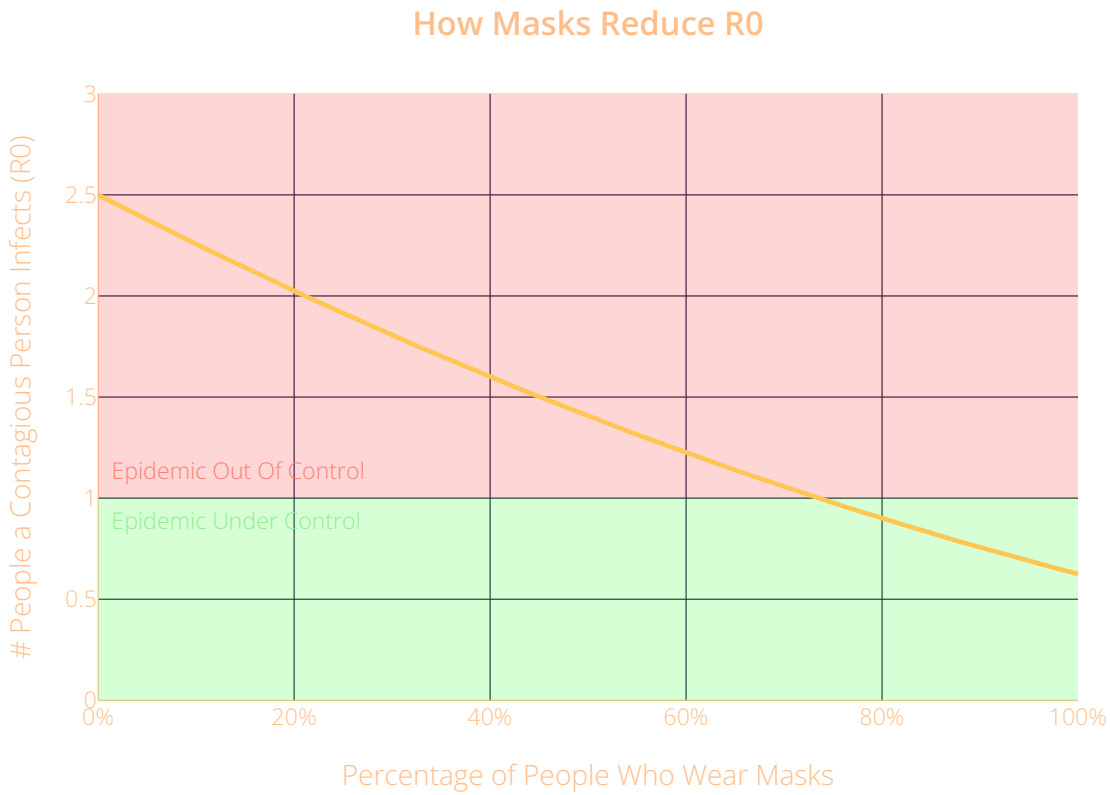
With this in mind, let's re-express the impact of masks in terms of R0. The graph below shows how R0 varies as mask-wearing increases.

You can use the first slider to vary R0, which for COVID-19 is between 2 and 3 (that's in the absence of other public health measures such as social distancing, which further reduce R0.) By varying the effectiveness of the masks, you can see how masks can help bring an epidemic under control.

R0: 2.5

Mask Effectiveness on Exhale: 50%

Mask Effectiveness on Inhale: 50%



To stop the spread of COVID-19, we need to keep R0 beneath 1. When this happens, on average, a contagious person will infect less than one person, and the epidemic will grind to a halt.

So how many people need to wear a 50% effective mask to stop the spread of COVID-19? What if masks were 75% effective? Or 90% effective? This interactive lets you predict answers to these questions.

An important caveat: people don't usually mix randomly. (Click to expand)

The Human Cost

We can take our understanding one step further by expressing the power of masks in more human terms. Masks save lives by reducing the chance of infection which, in turn, shrinks the extent of the epidemic.

As more people wear masks, R0 decreases. And as R0 decreases, so does the number of infected people. So we can get a clearer picture if instead of visualizing R0, we visualize the **infected fraction** of the population.

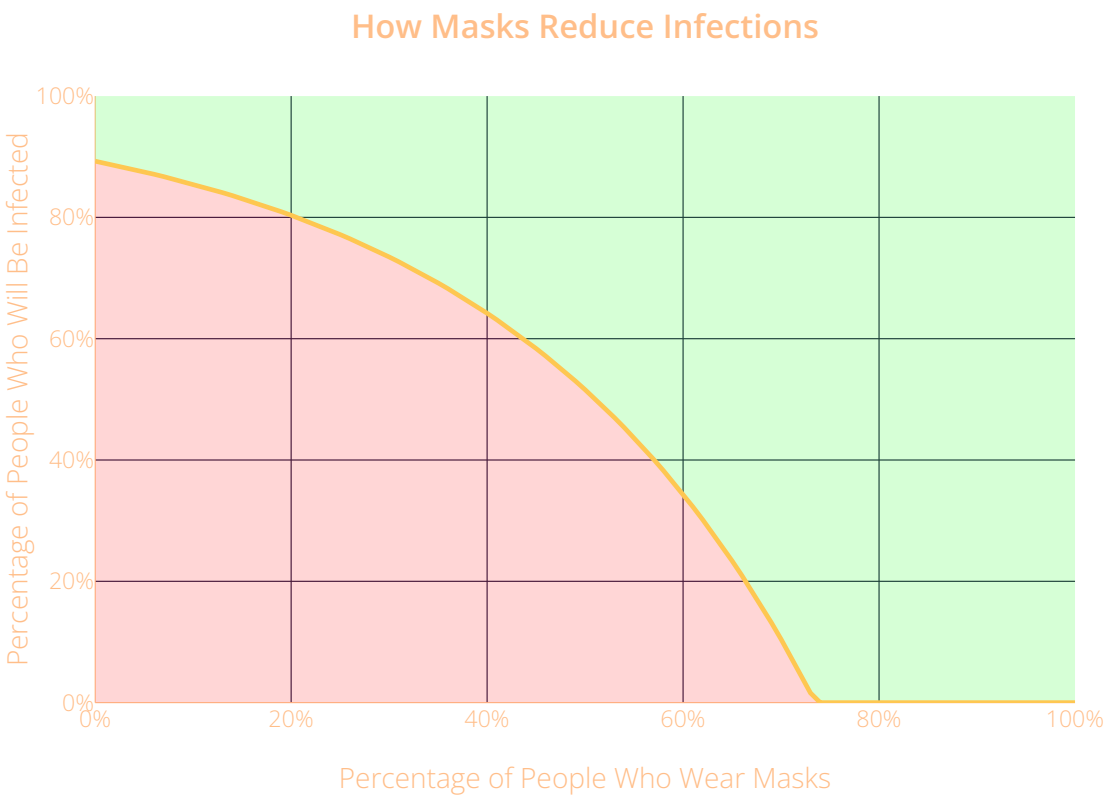
By using a widely-adopted mathematical model of epidemics known as an SIR model, we can relate R0 to the fraction of people who will eventually be infected. (To learn more about SIR models, I recommend watching this excellent video.)

Although this model is a considerable simplification (e.g. it assumes random mixing between people and no lockdowns), it offers us a ballpark estimate of the human cost of not wearing masks.

R0: 2.5

Mask Effectiveness on Exhale: 50%

Mask Effectiveness on Inhale: 50%



This hill-shaped curve shows us how masks influence the size of an epidemic. **As more people wear masks, the number of infections plummet.**

When very few people wear masks, we're at the top of the hill, and most people will eventually get infected. But every step to the right moves us further down. So even partially effective masks, when partially adopted, can help reduce the spread of COVID-19.

To completely stop the spread, we need to get to the bottom of this hill. But there's a silver lining: as more people wear masks, the hill grows steeper. Which means **masks provide greater returns to society as more people wear them**.

If enough people wear masks, we can reach the bottom of the hill, where the chance of infection is zero. This is how masks can end an epidemic. But masks can only end an epidemic if enough people wear them.

You might wonder how many people have to wear masks to end an epidemic. Well, that depends on how effective the masks are.

By playing with interactive above, you'll see that if masks were 50% effective, we'd need roughly three-quarters of the population to wear them to stop the spread of COVID-19. But if masks were 75% effective, we'd only need half the population to wear them to stop the spread.

The more effective the mask, the faster we can descend the hill. That's why it's important to wear a mask that tightly seals your mouth *and* nose, and is made from an effective filtering material.

We all want to get to the bottom of the hill and stop the spread of COVID-19. But you can't get there by yourself. Each person can only take a tiny step downwards.

However, when many people take this small step, together, we take a giant leap down the hill.

Together, we can get to the bottom of the hill.

Together, we can hit the brakes on COVID-19.

Credits & References

This essay was created by Aatish Bhatia in collaboration with Henry Reich.

Check out our companion video for a snappy visual take on the math of masks! The video was supported by the Heising-Simons Foundation. Here's the mask math calculator shown in the video.

Many thanks to Upasana Roy, Manu Prakash, David Fisman, Monica Gandhi, and

Vijay Ravikumar for their helpful feedback on drafts of this essay.

If you found this essay valuable and would like to see more work like this in future, you can **support my work on Patreon**.

Here are some informative resources on the filtering ability of common mask materials. While masks vary a lot in effectiveness depending on their material and fit, some materials can exceed 80% filtering ability when used in a tightly-sealed mask.

For the algebra enthusiasts among you (you know who you are), here's a writeup covering the math in more detail. The graphs in this essay extend the work of Brienen et al to account for the bidirectional effectiveness of masks.

The bidirectional model of masks underlying this essay was to my knowledge first published in a preprint by Tian et al (Table S3 and Fig S4). This was highlighted by Howard et al in their review article and accompanying essay, and further popularized by Zeynep Tufekci, Jeremy Howard, Trisha Greenhalgh in the Atlantic, and by Atul Gawande in the New Yorker, who writes, *"The more effective the mask, the bigger the impact."*

This text is published under a Creative Commons CC BY-NC 4.0 license. The source code is available on Github. The emojis are created by Twitter and were modified to include a custom mask design.

Thanks for reading, and stay safe! 😷